

NAVSEA Crane Radiation Test Report

Report No: NSWC C6054-2N5114-0001

Program: NASA GODDARD		Report Date: 1/31/2002
Generic Part No. 2N5114	Part Description: 40-V, 100-Ohm P-Channel FET	Manufacturer: Solitron
Package Type: TO-18	Date Code: 9518	Package Markings JV2N5114CDCD USA 9518 X02546
Detailed Test Specification: 2N5114 TID Test Plan	General Test Requirement:	Performance Specification MIL-PRF-19500/476B
Serial Number: 1, 2, 3, 4, 5, 6, 7, 8, 9, & 10 (manually marked)		Radiation Test Results See Appendix B, C, D, and E

1.0 Summary.

NAVSEA Crane was tasked to evaluate the total ionizing dose (TID) performance of this P-channel 40-V, 100-Ohm JFET (2N5114) to conditions specified by Christian Poivey, NASA-GSFC, Code 561, Greenbelt MD 20771. Prior to the test, Jeff Titus (NAVSEA) contacted Christian Poivey about the selected bias conditions. After some discussion via emails, the TID Test Plan was modified to the following TID conditions:

Revised 2N5114 TID Test Plan (12/28/2001)

Bias Condition	# of Test Samples	Drain	Gate	Source
1	3	5 V	0 V	5 V
2	3	0 V	5 V	0 V
3	2	0 V	0 V	0 V

NAVSEA Crane was tasked to perform these tests:

- Electrical Measurements (I_{GSS} , $I_{D_{SOFF}}$, $R_{D_{SON}}$, and $V_{G_{SOFF}}$), Gamma irradiations at dose levels of 2.5, 5, 10, 20, 30, and 50 krd(Si) using a dose rate less than 1 rd(Si)/s repeating electrical measurement after achieving the specified dose levels, and finally a Post-Radiation anneal test for 168 hrs @ 25°C with electrical measurements, afterwards. The actual anneal time was modified and electrical measurements were performed after 156 hours and a total of 210 hours instead of 168 hours.

Test results indicate that only $I_{D_{SS}}$ and I_{GSS} were sensitive to total ionizing dose effects at levels up to 50 krad(Si). Both of these parameters exceeded their specification limit at 50 krad(Si). The bias condition that produced the largest change was $V_D=V_S=V_G=0$ volts. $I_{D_{SS}}$ increased from 5.2 to 555 pA at 50 krad(Si) and to 584 pA after anneal. I_{GSS} increased from 8.5 to 994 pA at 50 krad(Si) and to 1080 pA after anneal. $R_{D_{SON}}$ slightly increased from 60 to 62 ohms at 50 krad(Si) and after anneal. $V_{G_{OFF}}$ increased from 7.70 to 7.75 volts at 50 krad(Si) and to 7.85 V after anneal. Detailed radiation data are provided in Appendix B, C, D, while graphical plots are provided in Appendix E.

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2.0 Applicable Documents.00

The major applicable documents, used to perform the TID tests, are listed here:

- a.) 2N5114 TID TEST PLAN NASA Supplied TID Test Plan
- b.) 2N5114 TID TP REVISED Modified Test plan via email communications
- c.) MIL-PRF-19500/476B Performance Specification P-Channel JFET
- d.) MIL-STD-750D Test Methods for Semiconductor Devices
 - Method 1019.4 Steady State Total Dose Irradiation Procedure
 - Method 3400 Conditions for Measurement of MOS FET Parameters
 - 3411.1 Gate Reverse Current (IG_OFF)
 - 3415.1 Drain Reverse Current (ID_OFF)
 - 3421.1 Static Drain to Source On Resistance (RDS_ON)
 - 3403.1 Gate to source Voltage (VGS_OFF)
- e.) ASTM Standard E668 Standard Practice for the Application of Thermoluminescence Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation Hardness Testing of Electronic Devices - Annual Book of ASTM Standards, Vol. 12.02: Nuclear (II), Solar, and Geothermal Energy, American Society for Testing and Materials
- f.) NAVSEA INST 4734.1 NAVSEA Metrology and Calibration Program
- g.) DOD-HDBK-263 Handbook - Electrostatic discharge sensitive devices

3.0 Handling Precautions.

Handling precautions were observed to minimize electrostatic discharge (ESD).

4.0 Electrical Test.

Electrical measurements were performed using either a Model Tektronix 370 curver tracer and/or an automated test system consisting of two Keithley 0237s and a controller. Two controls along with the 8 test samples were individually measured and recorded. The specified electrical tests are:

PARAMETER	CONDITION	PARAMETER	LIMIT
Gate Reverse Current (I_{GS_OFF})	$V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{GS_OFF}	$< 500 \text{ pA}$
Drain Current Cutoff (I_{GS_OFF})	$V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	I_{DS_OFF}	$< -500 \text{ pA}$
Drain-Source On Resistance (R_{DS_ON})	$I_{DS} = -1 \text{ mA};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON}	75 Ohm
Gate Source Cutoff (V_{GS_OFF})	$I_{DS} = -1 \text{ nA};$ $V_{DS} = -15 \text{ V}$	V_{GS_OFF}	$< 10 \text{ V}$

Note: Appendix A provides a summary of a visual inspection of the test samples.
 Appendix B provides a summary of the initial pre-radiation electrical test measurements.
 Appendix C provides a summary of the post-radiation electrical test measurements.
 Appendix D provides a summary of post-anneal electrical test measurements.
 Appendix E provides graphical responses of electrical test parameters.

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4.1 Test Conditions.

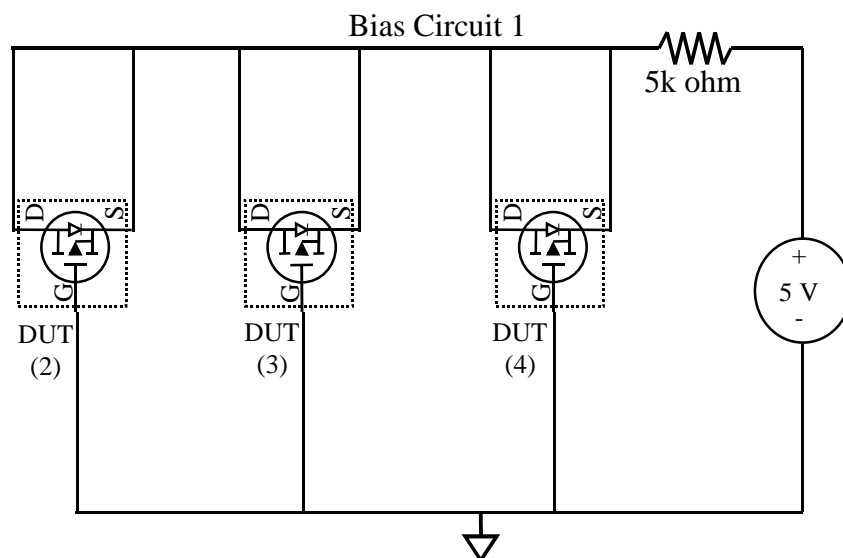
Test conditions were performed as specified by the applicable documents of 2.0 (specifically, the 2N5114 TID Test Plan Revised). All electrical measurements were performed at an ambient room temperature of $22\text{ }^{\circ}\text{C} \pm 3^{\circ}\text{C}$ and recorded prior to and after electrical tests.

5.0 Total Ionizing Dose (TID) Test.

Total ionizing dose tests were performed at the NAVSEA Crane Co-60 test facility using a J. L. Shepherd and Associates Model 81-22 Irradiator with a Model 484 Radiation Tunnel and Interlock Door Assembly. Test samples were placed inside a Pb/Al container to minimize dose enhancement effects caused by low-energy scattering. The desired dose rate is achieved by selecting different amounts of radioactivity and distance. For this test, the 8,000 curies source was used with the positioning table set at 670 mm.

5.1 Bias Circuit.

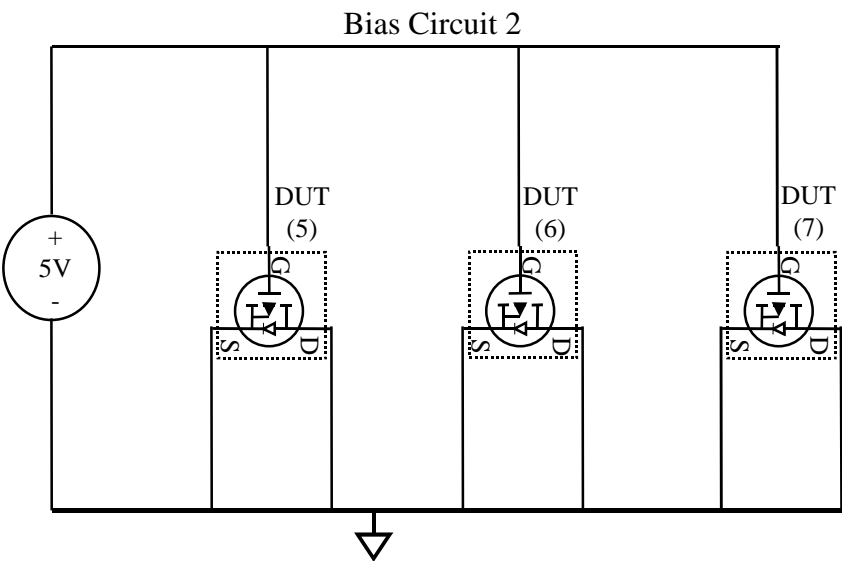
A custom bias board was designed and fabricated to perform the TID tests. The bias circuit conformed to the requirements of the test specification (see bias conditions - NASA 2N5114 TID Test Plan and Test Plan modifications of Summary, Section 1). Figure 1a depicts the TID insitu bias circuit used for three of the eight test samples ($V_D = V_S = 5\text{ V}$ and $V_G = 0\text{ V}$). Since the gated pn junction is hard on, the $5\text{ k}\Omega$ resistor was employed to limit the overall gate current to 1 mA . Figure 1b depicts the TID bias circuit used for the other three samples ($V_D = V_S = 0\text{ V}$ and $V_G = 5\text{ V}$). The other two samples were biased with all leads common ($V_D = V_S = V_G = 0\text{ V}$) as depicted in Figure 1c. This bias (all pins grounded) was found to produce the largest change in IDSS and IGSS. Figure 2 shows a pictorial representation of the of the TID bias board. Note that all eight test samples were exposed simultaneously.



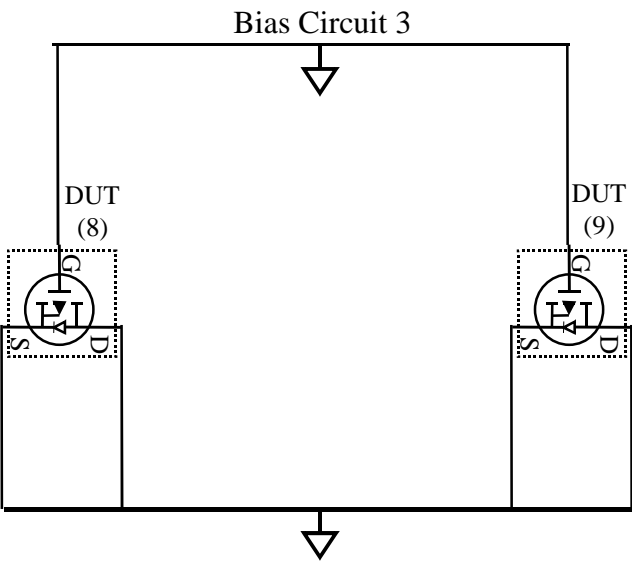
(a.) $V_D = V_S = 5\text{ V}$ and $V_G = 0\text{ V}$

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(b.) $V_D = V_S = 0\text{ V}$ and $V_G = 5\text{ V}$



(c.) $V_D = V_S = V_G = 0\text{ V}$

Figure 1. Bias circuits used in TID test.

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<p>2N5114</p> <p>S/N 2</p>	
<p>2N5114</p> <p>S/N 3</p>	
<p>2N5114</p> <p>S/N 4</p>	
<p>2N5114</p> <p>S/N 5</p>	
<p>2N5114</p> <p>S/N 6</p>	
<p>2N5114</p> <p>S/N 7</p>	
<p>2N5114</p> <p>S/N 8</p>	
<p>2N5114</p> <p>S/N 9</p>	

5.2 Dosimetry.

For total dose dosimetry, three ribbons were placed in a TLD holder and wrapped in a thin, (~ 0.001 inches) aluminum foil. The average reading of these three ribbons is used to determine the dose rate of the Co-60 source. For this test, TLDs were placed upon the top left socket, top right socket, bottom left socket, bottom right socket and the middle of all the sockets as depicted in Figure 3. Note, this dosimetry was used to determine exposure times for all tests performed. Table 2 provides a summary of the Co-60 Gamma Cell 220 source dosimetry.

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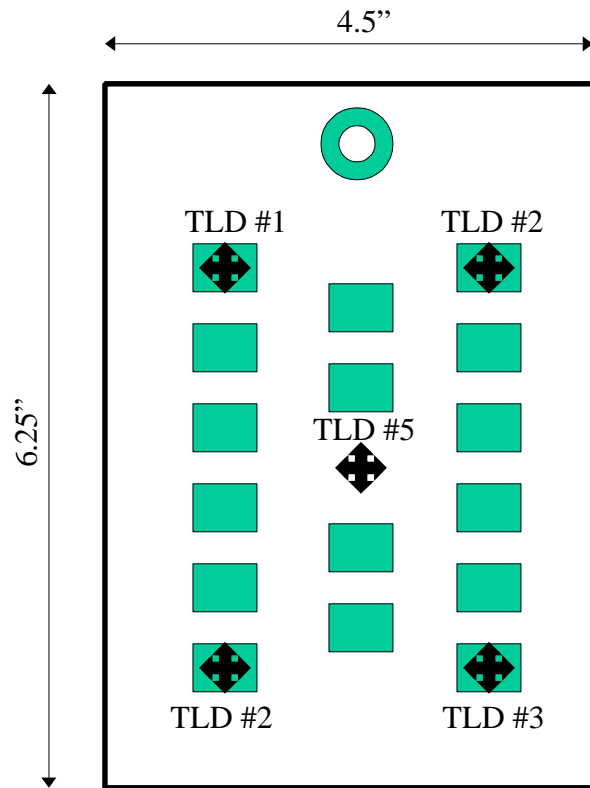


Figure 3. Pictorial Representation Showing TLD Placement.

Table 2. Verification of Co-60 Source

TLD Package	Slide Number	Avg. Dose Rd(CaF2)	Standard Deviation	Dose Rate [Rd(Si)/s]	Board Position
1	101	123.5	2.9%	0.8948	Top Left
2	102	124.2	0.6%	0.9000	Top Right
3	103	127.4	3.8%	0.9228	Bottom Left
4	104	119.7	1.4%	0.8677	Bottom Right
5	105	123.4	2.6%	0.8942	Middle
6	106	2489	1.6%	0.8861	Top Right

Based upon the dosimetry, the dose rate was determined to be 0.89 rd(Si)/s. To validate the first radiation level (and to verify the dose rate), another TLD (top right corner) was placed upon the TID board above the top right socket. The exposure time was set for 2809 seconds ($0.89 \times 2,809 = 2,500$), resulting in an average TLD reading of 2,489 rd(Si).

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Table 3 is a summary of the required exposure times to achieve radiation levels of 2.5, 5, 10, 20, 30, and 50 krd(Si) as required by the 2N5114 TID Test Plan. Table 3 also provides the times to perform the electrical measurements between each exposure.

Table 3. Summary of Exposure and Electrical Test Times of TID Test

Total Dose Test Date	Exposure Start Time	Exposure Stop Time	Total Dose Rd(Si)	Electrical Test Start Time	Electrical Test Stop Time
01/18/2001	9:42 AM	10:29 AM	2,500	10:31 AM	11:02 AM
01/18/2001	11:04 AM	11:51 AM	5,000	11:53 AM	12:06 PM
01/18/2001	12:09 PM	1:43 PM	10,000	1:44 PM	1:57 PM
01/18/2001	1:59 PM	5:07 PM	20,000	5:09 PM	5:27 PM
01/18/2001	5:29 PM	8:36 PM	30,000	8:37 PM	8:49 PM
01/18/2001	8:51 PM	3:06 AM	50,000	3:08 AM	3:23 AM

5.3 Post-Radiation Anneal Test.

Upon completion of the last exposure (50 krd(Si)) and electrical characterization, samples were annealed for 156 hours at 25 °C under similar bias conditions. After annealing, the samples were electrically characterized again. After electrical characterization, samples were annealed for an additional 54 hours at 25°C and electrically characterized again. This slight modification was performed to accommodate test personnel and the unusual test schedule (168 hr anneal would have required electrical test be conducted at 3:23 AM on a Saturday).

APPENDIX A. Visual Inspection Summary

Tagged S/N	Package Markings	Marking Verified	Comments
001	JV2N5114CDCD USA 9518 X02546	Yes	
002	JV2N5114CDCD USA 9518 X02546	Yes	
003	JV2N5114CDCD USA 9518 X02546	Yes	
004	JV2N5114CDCD USA 9518 X02546	Yes	
005	JV2N5114CDCD USA 9518 X02546	Yes	
006	JV2N5114CDCD USA 9518 X02546	Yes	
007	JV2N5114CDCD USA 9518 X02546	Yes	
008	JV2N5114CDCD USA 9518 X02546	Yes	
009	JV2N5114CDCD USA 9518 X02546	Yes	
010	JV2N5114CDCD USA 9518 X02546	Yes	

Note: Samples were received without assigned S/Ns. S/Ns were randomly assigned by NAVSEA and printed on the case using a permanent marker.

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Appendix B. Summary of Initial Electrical Test Data

S/N	I_{GS_OFF} $V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{DS_OFF} $V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON} $I_{DS} = -1 \text{ mA};$ $V_{GS} = 0 \text{ V}$	V_{GS_OFF} $I_{DS} = 1 \text{ mA}$ $V_{DS} = -15 \text{ V};$	V_{GS_OFF} $I_{DS} = 1 \text{ nA}$ $V_{DS} = -15 \text{ V};$	Allocated Test
001	8.22E-12	-4.86E-12	53	5.70	6.90	Control
002	1.03E-11	-6.47E-12	58	4.70	5.70	Bias 1
003	1.04E-11	-6.38E-12	58	4.70	6.50	Bias 1
004	9.40E-12	-5.76E-12	58	4.90	6.10	Bias 1
005	9.51E-12	-6.02E-12	60	4.60	5.90	Bias 2
006	8.75E-12	-5.36E-12	58	5.00	6.30	Bias 2
007	8.96E-12	-5.37E-12	58	4.70	5.90	Bias 2
008	1.03E-11	-6.22E-12	50	6.50	7.70	Bias 3
009	8.49E-12	-5.15E-12	54	5.70	7.10	Bias 3
010	8.15E-12	-4.90E-12	60	4.70	5.80	Control

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Appendix C. Summary of Electrical Parameters After each Radiation Level

Radiation Level 2,500 rd(Si)						
S/N	I_{GS_OFF} $V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{DS_OFF} $V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON} $I_{DS} = -1 \text{ mA};$ $V_{GS} = 0 \text{ V}$	V_{GS_OFF} $I_{DS} = 1 \text{ mA}$ $V_{DS} = -15 \text{ V};$	V_{GS_OFF} $I_{DS} = 1 \text{ nA}$ $V_{DS} = -15 \text{ V};$	Allocated Test
001	6.57E-12	-3.86E-12	53	5.70	6.90	Control
002	1.02E-10	-5.94E-11	58	4.70	5.90	Bias 1
003	8.04E-11	-4.60E-11	58	4.70	6.40	Bias 1
004	8.58E-11	-4.89E-11	58	4.85	6.10	Bias 1
005	4.43E-11	-2.49E-11	60	4.60	5.90	Bias 2
006	4.48E-11	-2.50E-11	58	5.00	6.50	Bias 2
007	4.78E-11	-2.66E-11	60	4.70	5.90	Bias 2
008	7.71E-11	-4.42E-11	50	6.50	7.70	Bias 3
009	6.52E-11	-3.70E-11	55	5.70	7.10	Bias 3
010	6.05E-12	-3.59E-12	60	4.70	5.80	Control
Radiation Level 5,000 rd(Si)						
S/N	I_{GS_OFF} $V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{DS_OFF} $V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON} $I_{DS} = -1 \text{ mA};$ $V_{GS} = 0 \text{ V}$	V_{GS_OFF} $I_{DS} = 1 \text{ mA}$ $V_{DS} = -15 \text{ V};$	V_{GS_OFF} $I_{DS} = 1 \text{ nA}$ $V_{DS} = -15 \text{ V};$	Radiation Sample Description
001	6.29E-12	-3.67E-12	54	5.70	6.90	Control
002	1.33E-10	-7.52E-11	58	4.70	5.90	Bias 1
003	1.20E-10	-6.77E-11	58	4.70	6.40	Bias 1
004	1.30E-10	-7.36E-11	58	4.85	6.10	Bias 1
005	1.15E-10	-6.58E-11	62	4.60	5.90	Bias 2
006	7.64E-11	-4.17E-11	58	5.00	6.50	Bias 2
007	8.09E-11	-4.43E-11	60	4.70	5.90	Bias 2
008	1.04E-10	-5.85E-11	50	6.50	7.70	Bias 3
009	1.39E-10	-8.04E-11	56	5.70	7.10	Bias 3
010	5.95E-12	-3.52E-12	60	4.70	5.90	Control
Radiation Level 10,000 rd(Si)						
S/N	I_{GS_OFF} $V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{DS_OFF} $V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON} $I_{DS} = -1 \text{ mA};$ $V_{GS} = 0 \text{ V}$	V_{GS_OFF} $I_{DS} = 1 \text{ mA}$ $V_{DS} = -15 \text{ V};$	V_{GS_OFF} $I_{DS} = 1 \text{ nA}$ $V_{DS} = -15 \text{ V};$	Radiation Sample Description
001	6.58E-12	-3.85E-12	54	5.70	6.90	Control
002	2.02E-10	-1.13E-10	58	4.70	5.90	Bias 1
003	1.69E-10	-9.36E-11	58	4.70	6.40	Bias 1
004	1.89E-10	-1.06E-10	58	4.90	6.10	Bias 1
005	1.25E-10	-6.65E-11	60	4.50	5.90	Bias 2
006	1.23E-10	-6.58E-11	58	5.00	6.50	Bias 2
007	1.22E-10	-6.49E-11	60	4.70	5.90	Bias 2
008	2.03E-10	-1.15E-10	52	6.50	7.70	Bias 3
009	2.01E-10	-1.13E-10	56	5.70	7.10	Bias 3
010	6.58E-12	-3.92E-12	60	4.70	5.90	Control

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Appendix C. Summary of Electrical Parameters After each Radiation Level (CONT.)

Radiation Level 20,000 rd(Si)						
S/N	I_{GS_OFF} $V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{DS_OFF} $V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON} $I_{DS} = -1 \text{ mA};$ $V_{GS} = 0 \text{ V}$	V_{GS_OFF} $I_{DS} = 1 \text{ mA}$ $V_{DS} = -15 \text{ V};$	V_{GS_OFF} $I_{DS} = 1 \text{ nA}$ $V_{DS} = -15 \text{ V};$	Allocated Test
001	6.79E-12	-4.04E-12	54	5.70	6.90	Control
002	4.81E-10	-2.73E-10	58	4.70	5.70	Bias 1
003	4.64E-10	-2.64E-10	60	4.70	6.40	Bias 1
004	4.81E-10	-2.74E-10	60	4.90	6.10	Bias 1
005	3.84E-10	-2.15E-10	62	4.50	5.90	Bias 2
006	3.56E-10	-1.97E-10	58	5.00	6.50	Bias 2
007	3.47E-10	-1.92E-10	60	4.70	5.90	Bias 2
008	3.85E-10	-2.16E-10	52	6.50	7.70	Bias 3
009	4.18E-10	-2.37E-10	56	5.70	7.10	Bias 3
010	6.80E-12	-4.06E-12	60	4.70	5.90	Control
Radiation Level 30,000 rd(Si)						
S/N	I_{GS_OFF} $V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{DS_OFF} $V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON} $I_{DS} = -1 \text{ mA};$ $V_{GS} = 0 \text{ V}$	V_{GS_OFF} $I_{DS} = 1 \text{ mA}$ $V_{DS} = -15 \text{ V};$	V_{GS_OFF} $I_{DS} = 1 \text{ nA}$ $V_{DS} = -15 \text{ V};$	Radiation Sample Description
001	6.04E-12	-3.55E-12	54	5.70	6.85	Control
002	6.26E-10	-3.49E-10	58	4.65	5.75	Bias 1
003	5.35E-10	-3.01E-10	58	4.75	6.40	Bias 1
004	5.42E-10	-3.04E-10	58	4.85	6.25	Bias 1
005	4.40E-10	-2.41E-10	62	4.55	5.85	Bias 2
006	4.20E-10	-2.28E-10	58	5.00	6.50	Bias 2
007	4.11E-10	-2.24E-10	60	4.75	6.05	Bias 2
008	5.56E-10	-3.12E-10	52	6.50	7.70	Bias 3
009	5.77E-10	-3.24E-10	56	5.75	7.25	Bias 3
010	6.47E-12	-3.82E-12	60	4.65	5.95	Control
Radiation Level 50,000 rd(Si)						
S/N	I_{GS_OFF} $V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{DS_OFF} $V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON} $I_{DS} = -1 \text{ mA};$ $V_{GS} = 0 \text{ V}$	V_{GS_OFF} $I_{DS} = 1 \text{ mA}$ $V_{DS} = -15 \text{ V};$	V_{GS_OFF} $I_{DS} = 1 \text{ nA}$ $V_{DS} = -15 \text{ V};$	Radiation Sample Description
001	6.02E-12	-3.55E-12	54	5.70	6.85	Control
002	9.43E-10	-5.22E-10	58	4.65	5.80	Bias 1
003	7.10E-10	-3.92E-10	58	4.75	6.45	Bias 1
004	7.68E-10	-4.27E-10	58	4.85	6.25	Bias 1
005	6.25E-10	-3.40E-10	62	4.55	5.85	Bias 2
006	6.68E-10	-3.66E-10	58	5.00	6.50	Bias 2
007	6.35E-10	-3.45E-10	60	4.75	6.05	Bias 2
008	8.67E-10	-4.84E-10	52	6.50	7.75	Bias 3
009	9.94E-10	-5.55E-10	56	5.75	7.20	Bias 3
010	5.96E-12	-3.40E-12	60	4.65	5.85	Control

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0Appendix D. Summary of Electrical Tests After Anneal

Anneal: 156 hours @ 25 °C - (Post-radiation level of 50,000 rd(Si))						
S/N	I_{GS_OFF} $V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{DS_OFF} $V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON} $I_{DS} = -1 \text{ mA};$ $V_{GS} = 0 \text{ V}$	V_{GS_OFF} $I_{DS} = 1 \text{ mA}$ $V_{DS} = -15 \text{ V};$	V_{GS_OFF} $I_{DS} = 1 \text{ nA}$ $V_{DS} = -15 \text{ V};$	Allocated Test
001	5.87E-12	-3.43E-12	52.0	5.70	6.95	Control
002	8.63E-10	-4.97E-10	58.0	4.65	5.85	Bias 1
003	7.48E-10	-4.31E-10	58.0	4.75	6.45	Bias 1
004	6.91E-10	-3.96E-10	58.0	4.85	6.25	Bias 1
005	5.09E-10	-2.81E-10	62.0	4.55	5.85	Bias 2
006	5.77E-10	-3.23E-10	58.0	5.00	6.50	Bias 2
007	5.13E-10	-2.84E-10	60.0	4.75	6.05	Bias 2
008	1.08E-09	-6.16E-10	52.0	6.55	7.75	Bias 3
009	1.04E-09	-5.84E-10	54.0	5.75	7.20	Bias 3
010	6.93E-12	-4.17E-12	60.0	4.65	5.95	Control
Anneal: 210 hours @ 25 °C - (Post-radiation level of 50,000 rd(Si))						
S/N	I_{GS_OFF} $V_{DS} = 0 \text{ V};$ $V_{GS} = 20 \text{ V}$	I_{DS_OFF} $V_{DS} = -15 \text{ V};$ $V_{GS} = 12 \text{ V}$	R_{DS_ON} $I_{DS} = -1 \text{ mA};$ $V_{GS} = 0 \text{ V}$	V_{GS_OFF} $I_{DS} = 1 \text{ mA}$ $V_{DS} = -15 \text{ V};$	V_{GS_OFF} $I_{DS} = 1 \text{ nA}$ $V_{DS} = -15 \text{ V};$	Allocated Test
001	8.08E-12	-4.97E-12	54.0	5.70	6.85	Control
002	9.24E-10	-5.35E-10	58.0	4.65	5.85	Bias 1
003	7.00E-10	-4.00E-10	58.0	4.75	6.45	Bias 1
004	7.34E-10	-4.23E-10	58.0	4.85	6.25	Bias 1
005	5.54E-10	-3.10E-10	62.0	4.55	5.85	Bias 2
006	5.34E-10	-2.98E-10	58.0	5.00	6.50	Bias 2
007	5.32E-10	-2.97E-10	60.0	4.75	6.05	Bias 2
008	1.06E-09	-6.00E-10	52.0	6.55	7.85	Bias 3
009	1.07E-09	-6.01E-10	56.0	5.75	7.20	Bias 3
010	6.75E-12	-4.08E-12	60.0	4.65	5.95	Control

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Appendix E. Graphical Summary of Electrical Tests Results

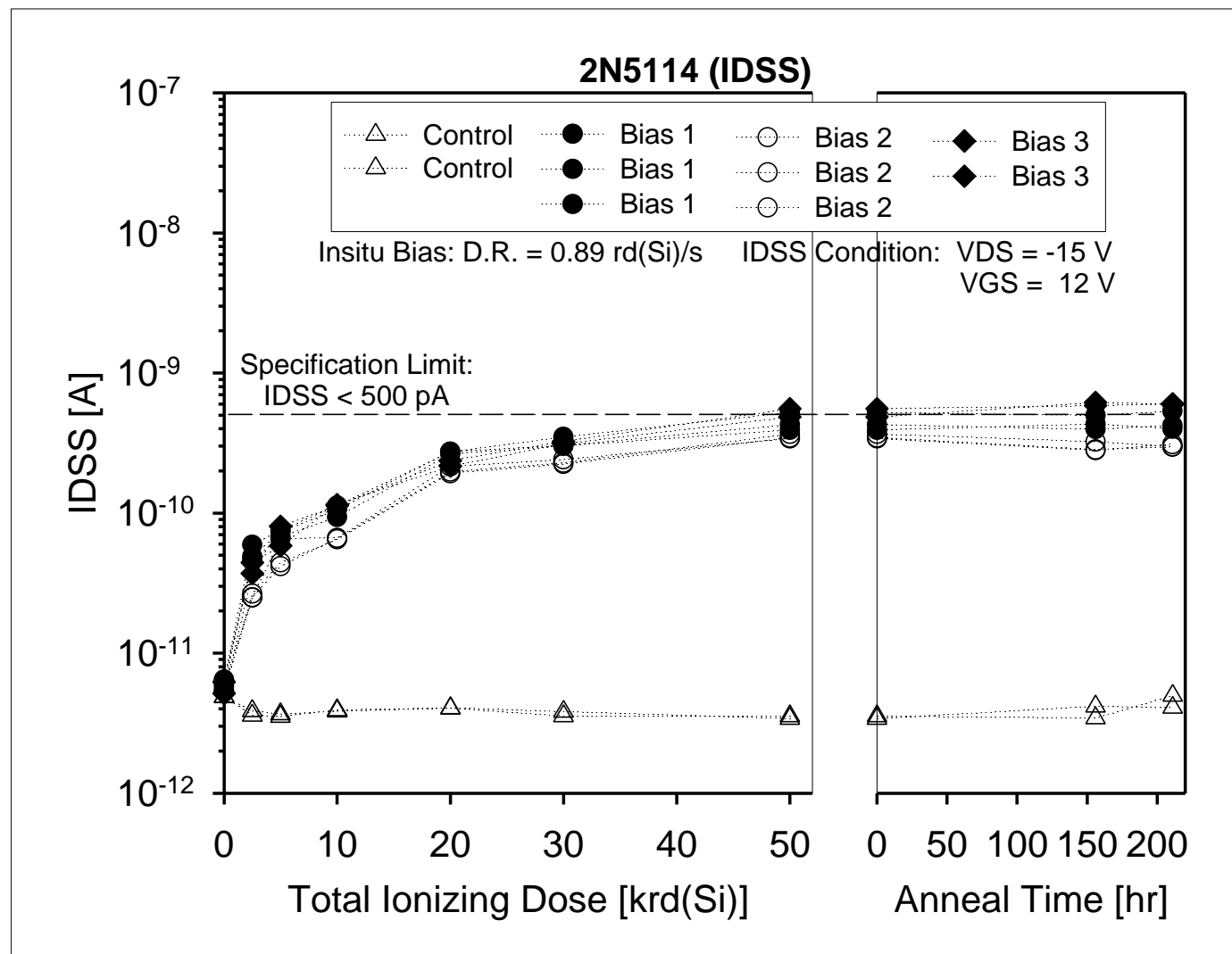


Fig. E1: IDSS responses of TID samples

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Appendix E. Graphical Summary Continued

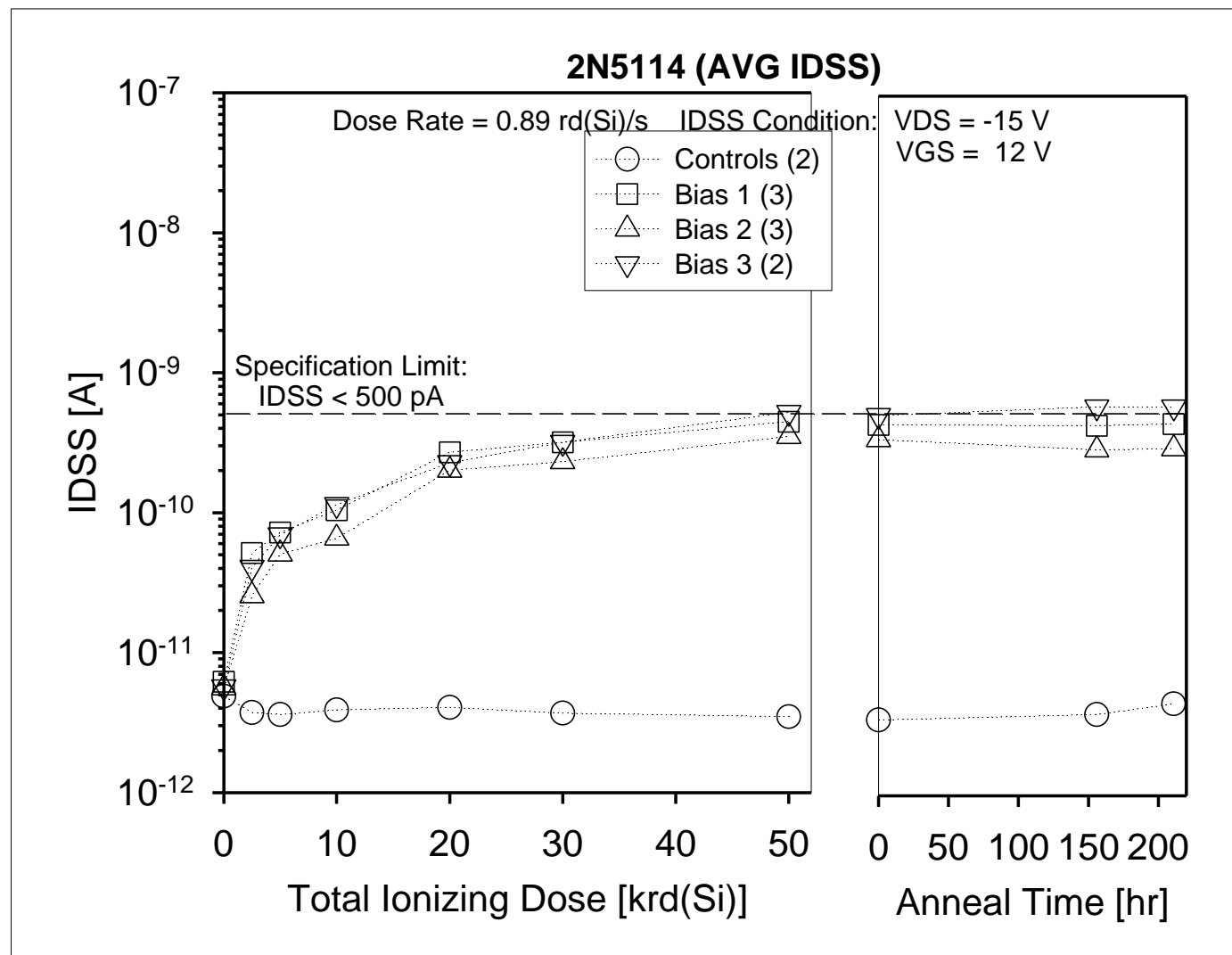


Fig. E2: Average IDSS response of each condition

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Appendix E. Graphical Summary Continued

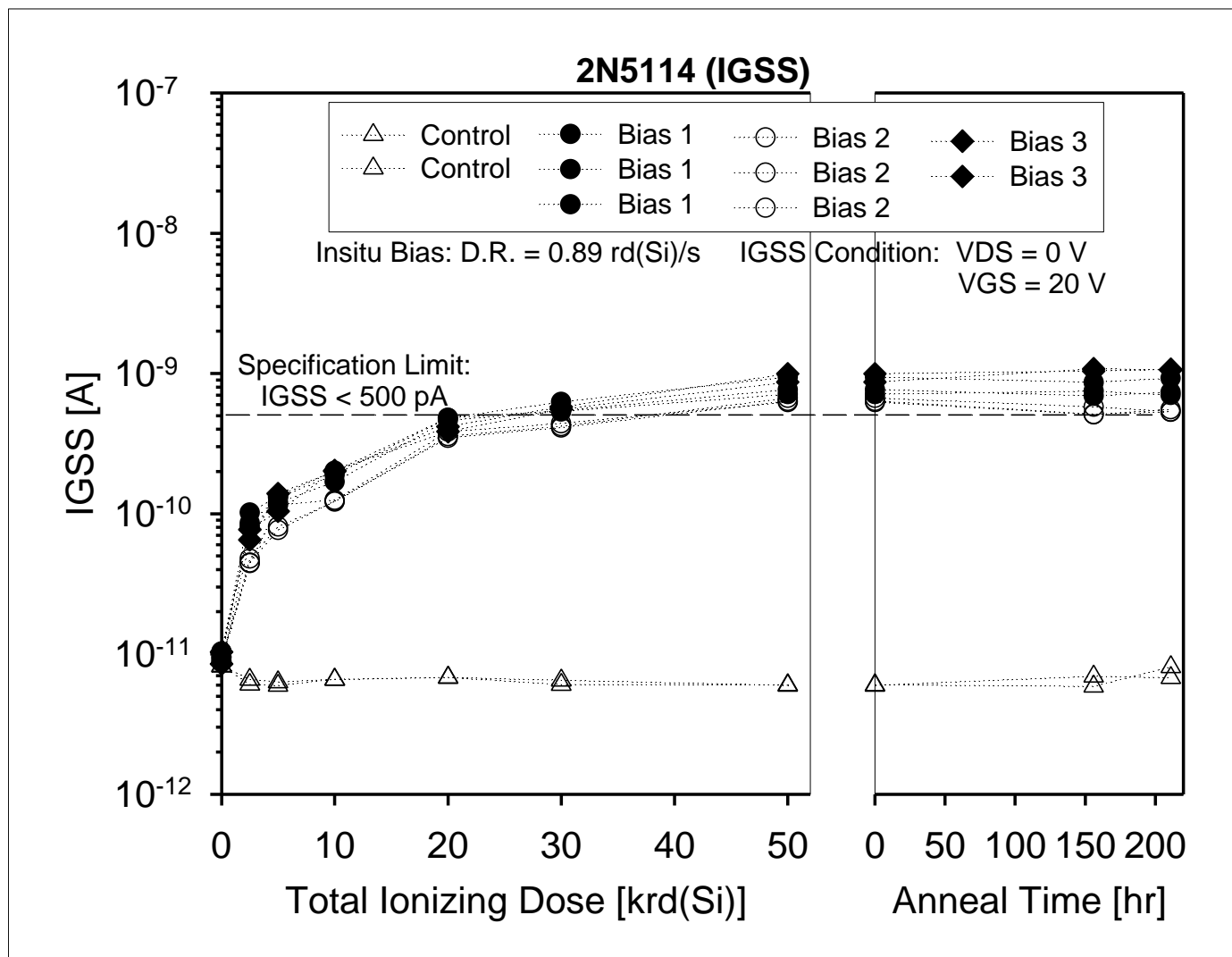


Fig. E3: IGSS responses of TID samples

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Appendix E. Graphical Summary Continued

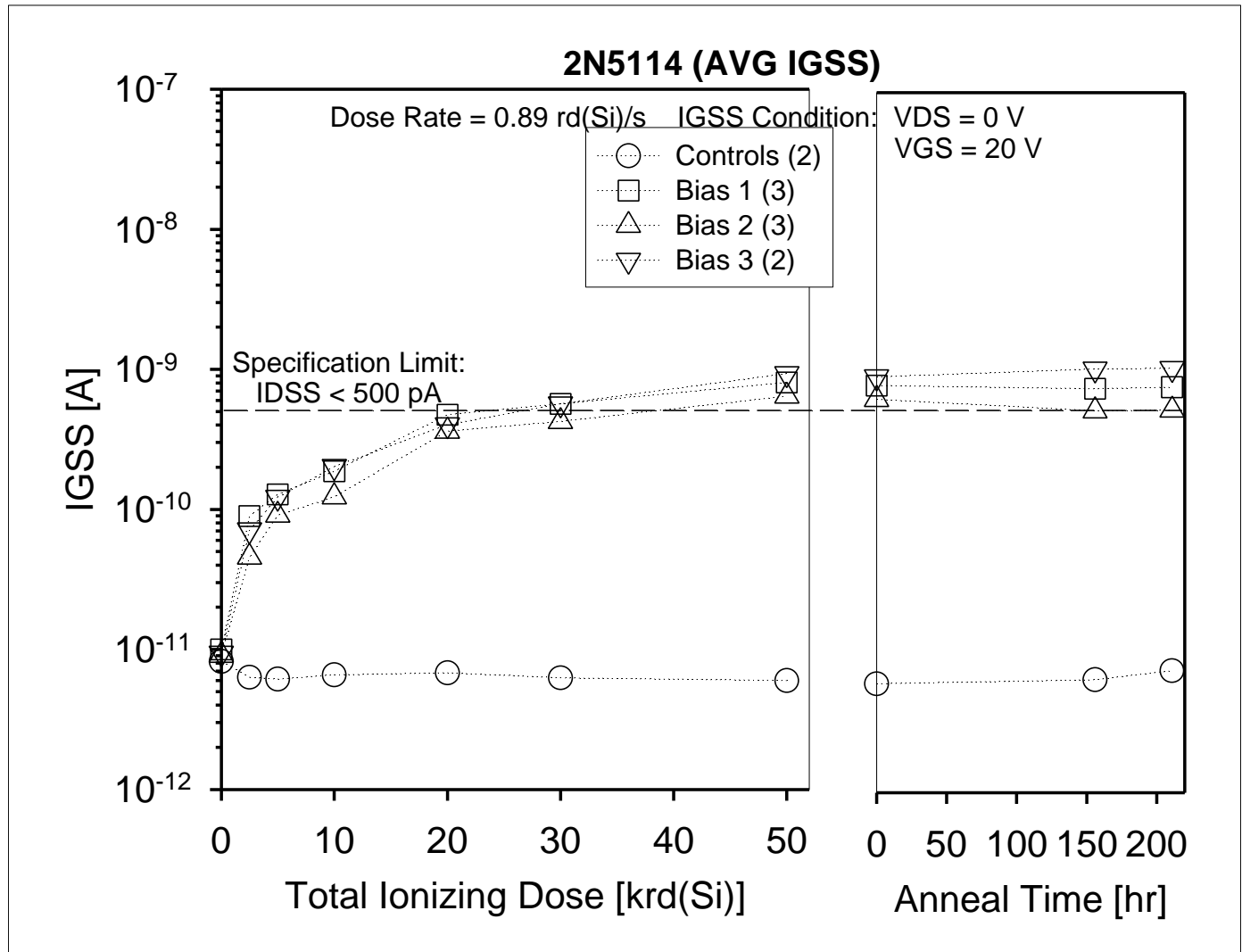


Fig. E4: Average IGSS response of each condition

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Appendix E. Graphical Summary Continued

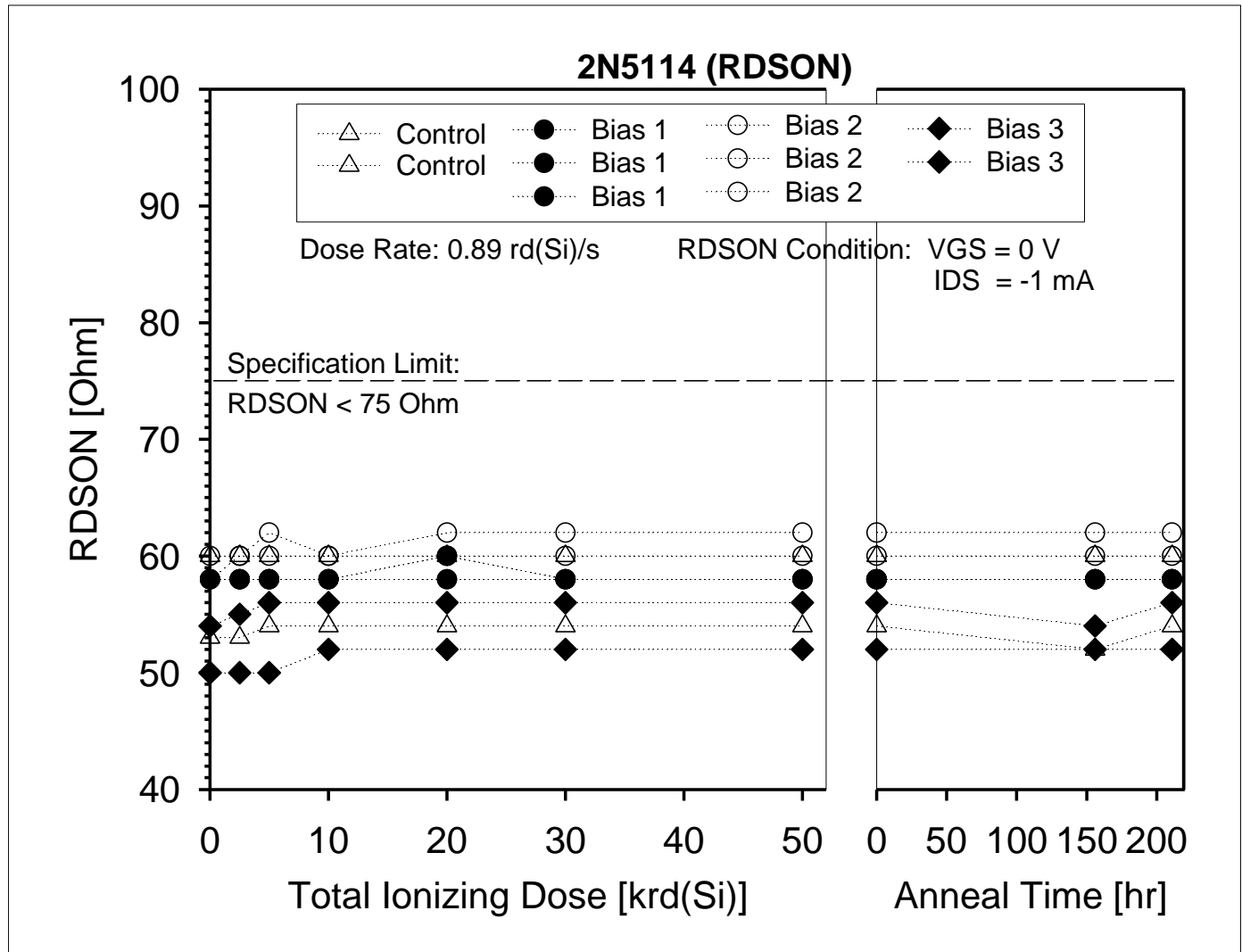


Fig. E5: RDSN response of TID samples

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Appendix E. Graphical Summary Continued

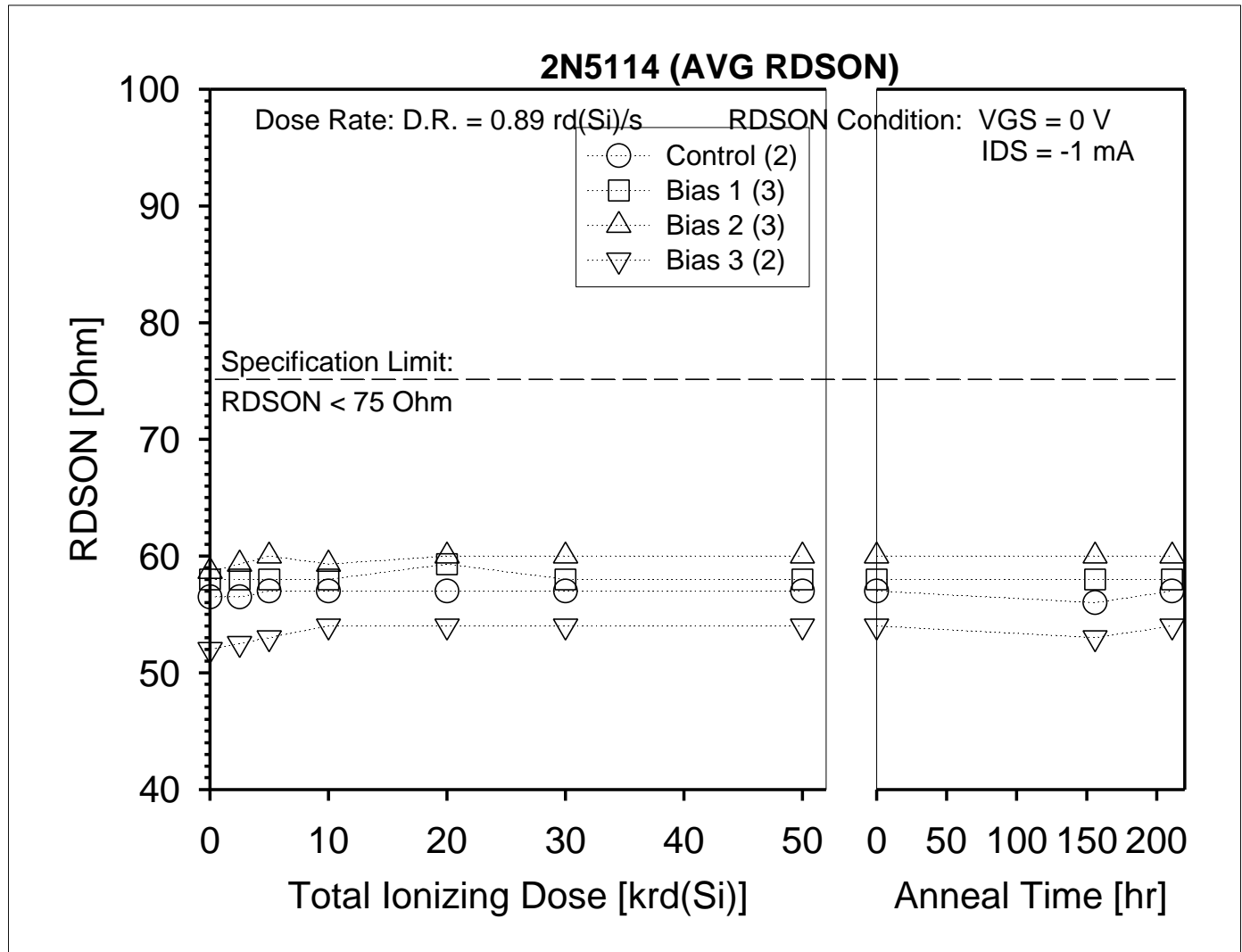


Fig. E6: Average RDSON response of each TID condition

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Appendix E. Graphical Summary Continued

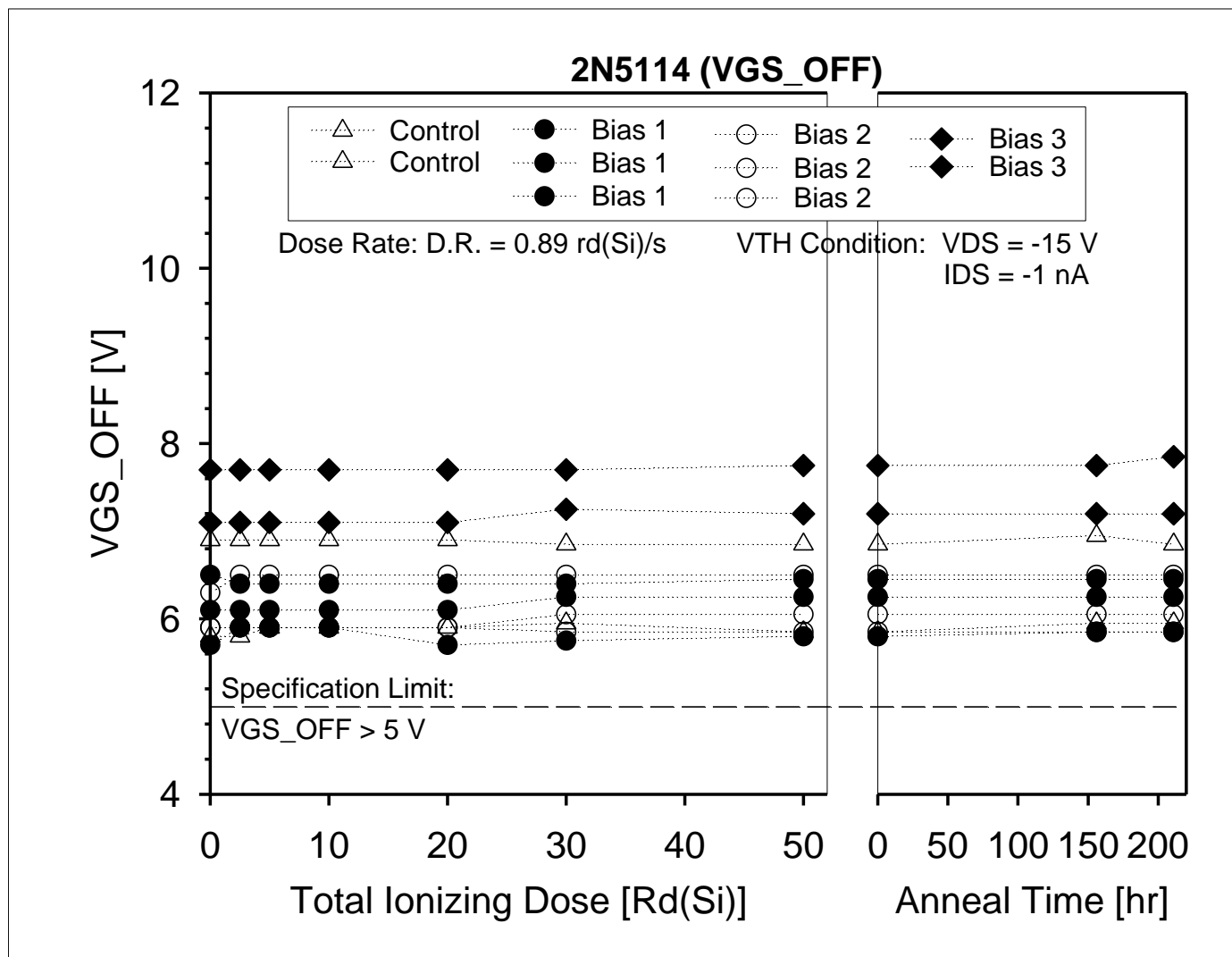


Fig. E7: VGSOFF response of TID samples

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Appendix E. Graphical Summary Continued

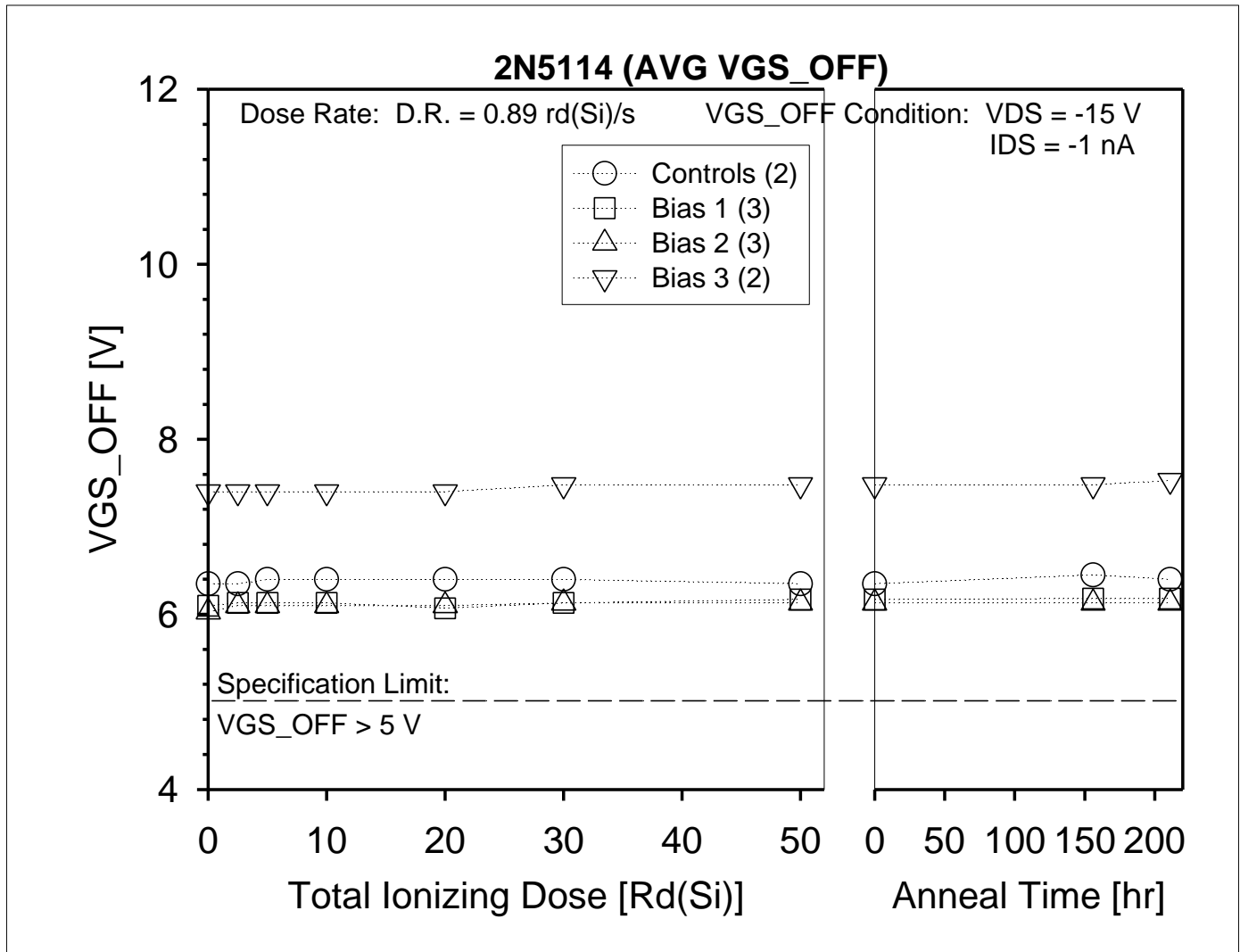


Fig. E8: Average VGSOFF response of each TID condition